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An Alternative Profile for the PVC Cell used in NOVA Experiment

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Introduction

The initial proposed design for the PVC cell for the Nova experiment is 6.0 cm x 3.88 cm with a 3 mm (side wall) x 2 mm (web) x 3 mm (corner radius). Stress calculation revealed that the maximum stress is 1,350 psi under a 19 psi hydrostatic pressure for an interior cell. One can maintain the working stress below 1,000 psi by gluing the vertical and horizontal planes together (Nova# 65), but this sets stringent QA requirements during assembly, and may require significant additional amounts of epoxy. This study is explores variants of the profile of the cell to reduce the stress and minimize gluing requirement without adding material. A different profile of the end cell has also been developed.

Interior Cell

The original internal size for the interior cell is 3.8 cm x 6 cm, using a 3 mm thick sheath wall thickness and a 2 mm thick web, with a 1/8" corner radius. The stress calculation in Fig 1 shows that the maximum stress is 1,350 psi. It occurs in the corner of the cell where the maximum bending moment is. By increasing the corner radius to 3/8" as shown in Fig 2, the working stress is dramatically reduced to about 600 psi. This 50% of the reduction in stress is a very significant. It relaxes the requirement of gluing two planes together to reduce stress < 1,000 psi under the hydrostatic pressure. We must still meet the much easier requirements to transfer, in shear, the weight of the horizontal extrusions to the vertical ones, and to resist, also in shear, the buckling forces for multi-plane blocks.

However, 3/8" corner radius (Fig. 2) will result a 18% more material than 1/8" radius as a penalty, both in materials cost and by reducing the ratio of active over dead mass. Based on the stress distribution, a further reduction in material seemed to be possible by modifying the backside slightly to form a "scallop shape" as shown in Fig 4. The maximum working stress is about 715 psi without adding any extra material as summarized in Table 1. A structure with a lower working stress will have a less pronounced effect for the creep. The stability calculation also demonstrates that the cell profile with a 3/8" corner radius & scallop backside offers a superior structure performance against the buckling. The detail is attached on Appendix A.

The light sealing or other impacts due to this curved backside should be addressed further in detail. One alternative would be to use ¼" radius while keeping a flat backside. It will, however, result a 7% additional material as shown in case 4, table 1.

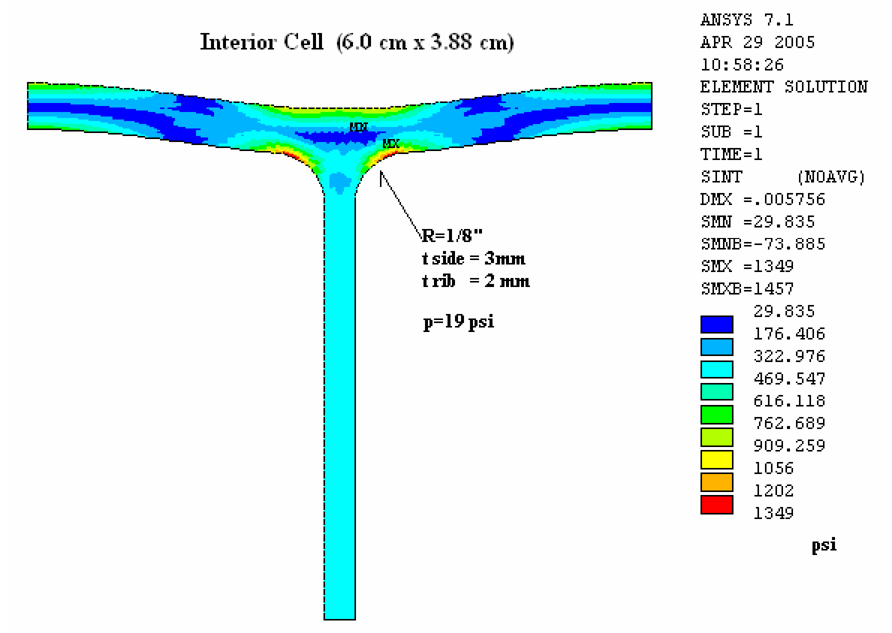

Fig 1 The initial profile for the interior cell with R=1/8" And flat backside __ stress

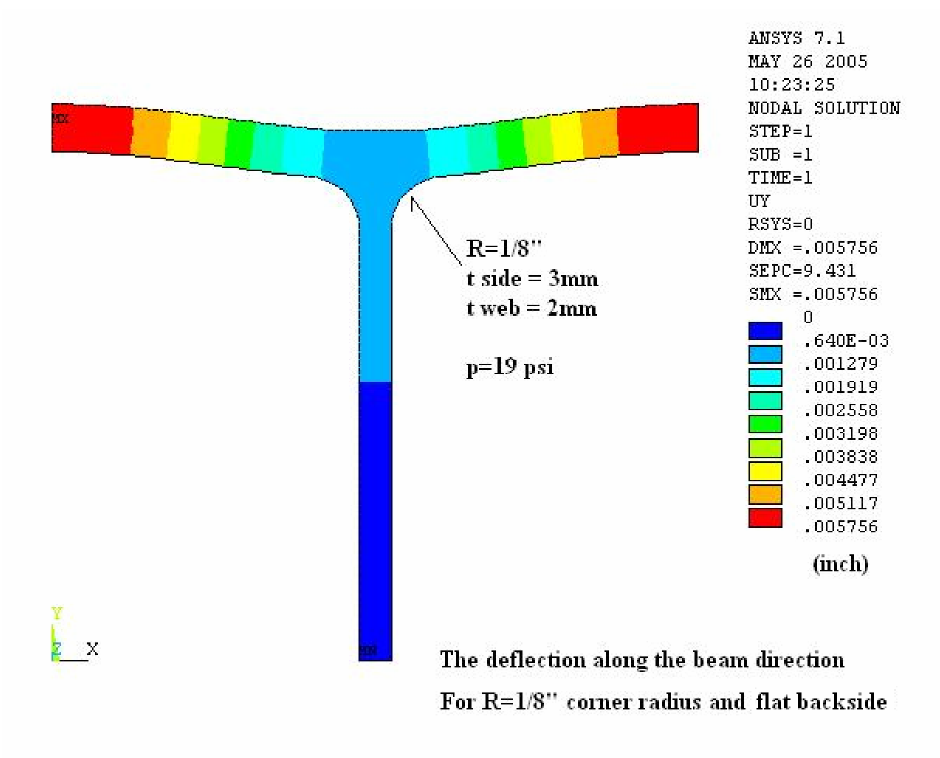

Fig 1a The initial profile for the interior cell with R=1/8" And flat backside__deflection

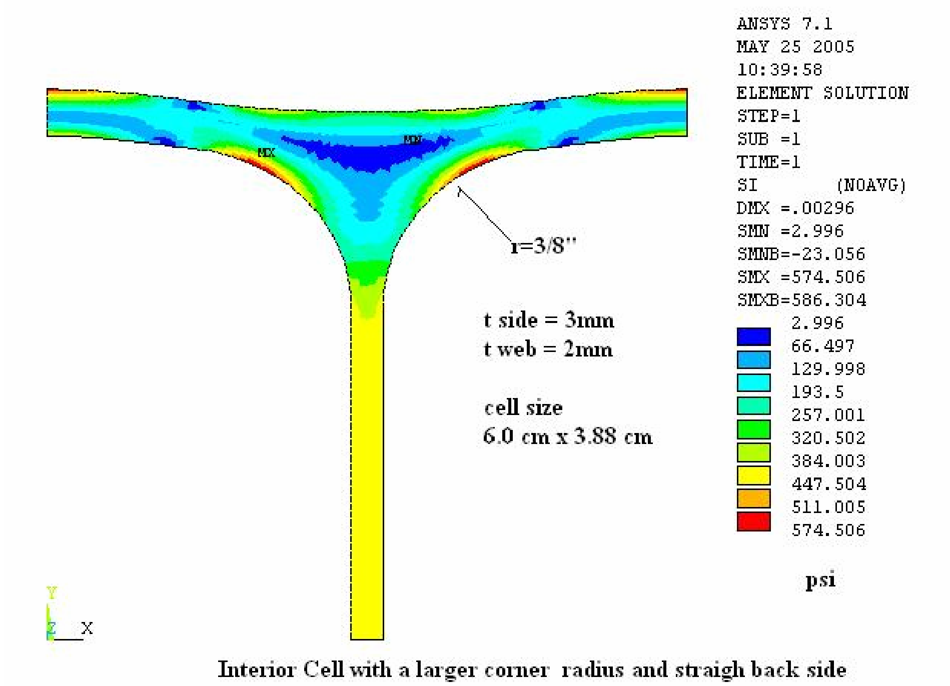

Fig 2 The interior cell with a larger corner radius R=3/8" and flat backside __ stress

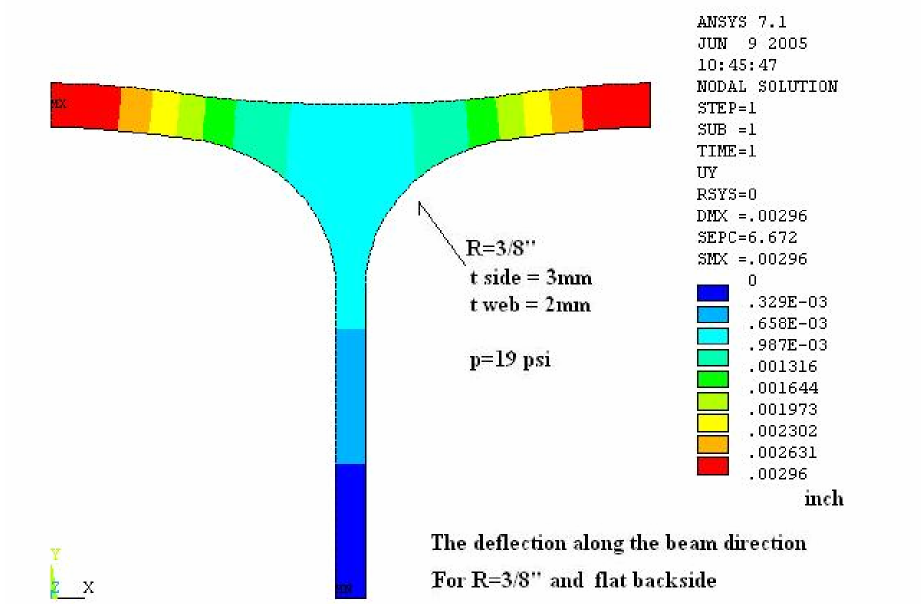

Fig 2a The interior cell with a larger corner radius R=3/8" and flat backside __ deflection

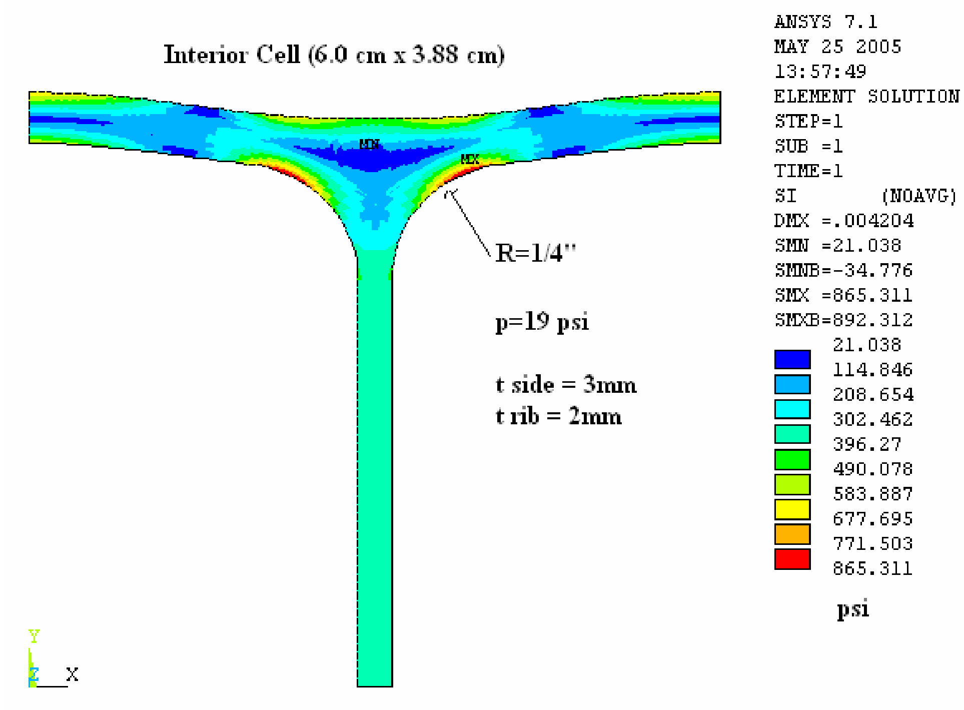

Fig 3 The interior cell with a larger corner radius R=1/4" and a flat backside_ stress

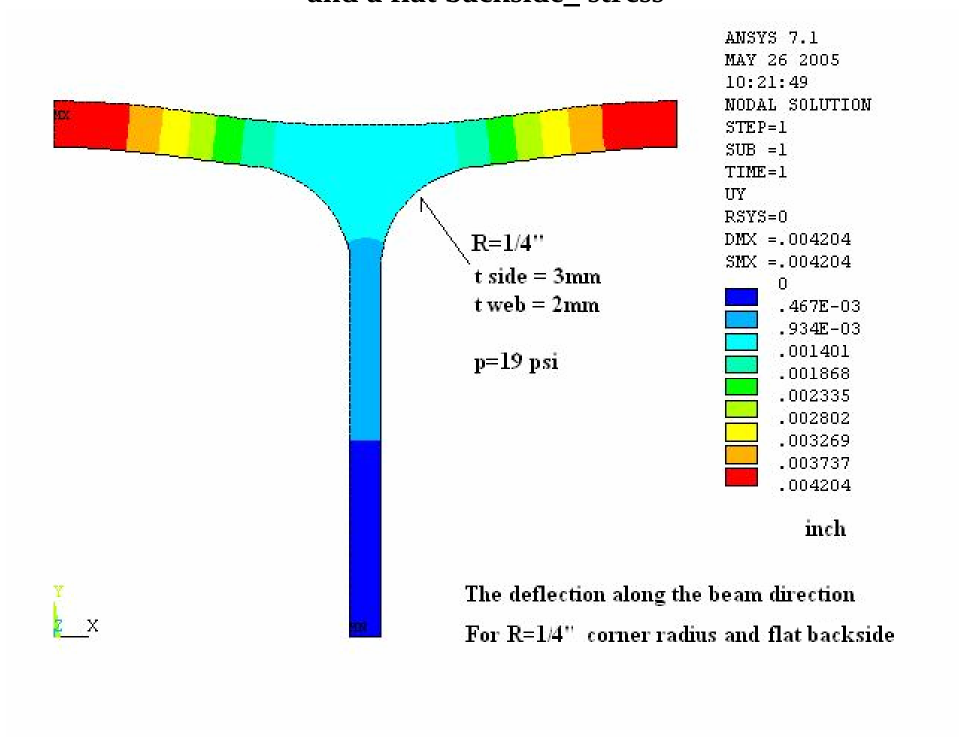

Fig 3a The interior cell with a larger corner radius R=1/4" and a flat backside_ deflection

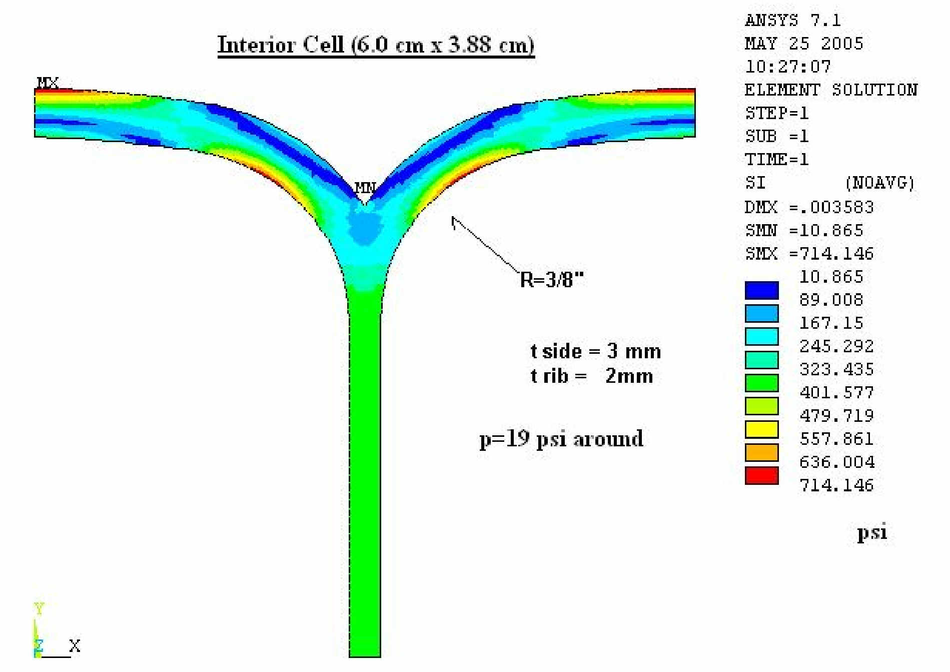

Fig 4 The interior cell with a larger corner radius R=3/8" and a scallop backside __ stress

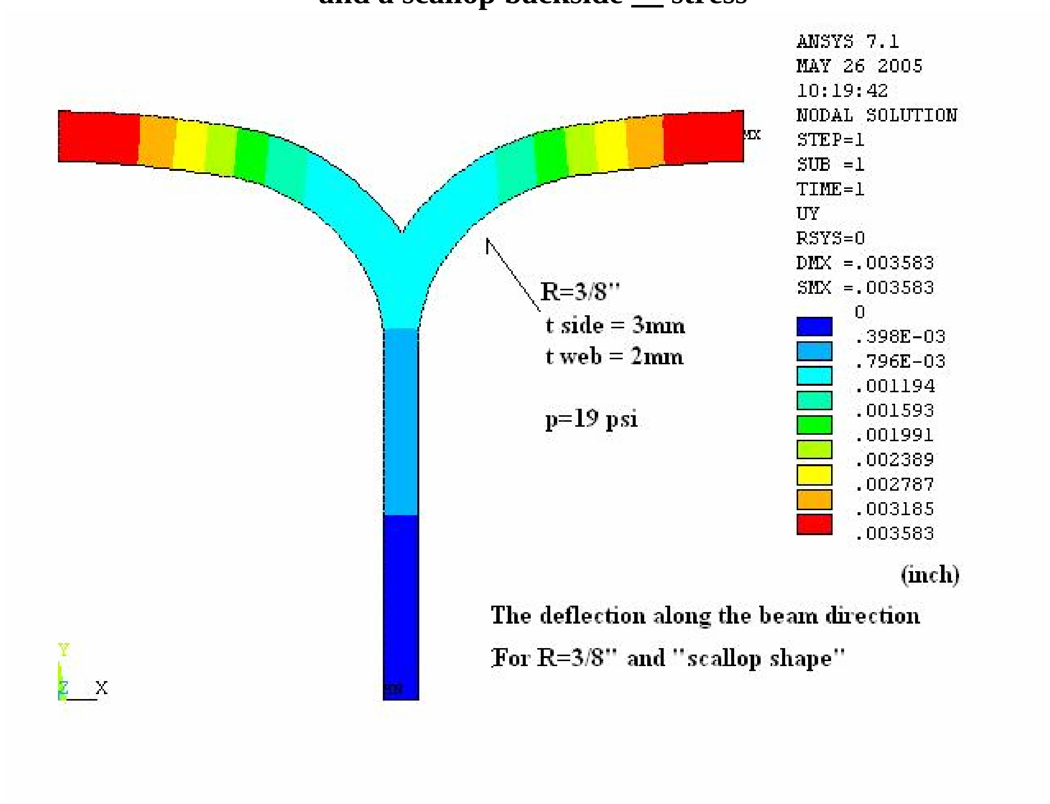

Fig 4a The interior cell with a larger corner radius R=3/8" and a scallop backside__ deflection

Table 1 Summary of Result for a Single Interior Cell under 19 psi

Case	Stress (psi)	Stress ratio*	Cross section area for a single interior cell(in^2)	Area ratio *	Single Cell Deflection (mils)	Deflection Ratio*
1) 1/8”& flat backside	1,350	1	0.5788	1	5.7	1
2) 3/8”& flat backside	575	0.44	0.6861	1.185	2.96	0.52
3) 3/8”& scallop backside	715	0.52	0.5758	0.995	3.5	0.61
4) ¼” & flat backside	865	0.64	0.6191	1.07	4.2	0.74

*Note:
The ratio is calculated based on the 1/8” & flat backside as a reference.

Plane-to-plane gluing

We expect to make a glue dispensing machine. Covering the whole area with epoxy is not required to resist forces, is very expensive, and requires a very large applied pressure to spread the glue. For the 2005 proposal we anticipated glue dots on a 1 inch grid, for a total of 382,060 dots per plane. With the scalloped cell design, it is reasonable to place a glue dot at every intersection of scallops (each cell has actually an 18 mm wide flat top), for a total number of 147,456 dots. The glue machine must be capable of placing the dots to a 1 cm or so accuracy, which is not difficult. If we stay with the glue dot volume of 0.22 cm^3 the glue dot spreads to a 2 cm x 2 cm contact area for a glue thickness of 0.5 mm. This is more than adequate, and may be reduced with further tests. For these numbers, the epoxy cost per plane drops from $ 1358 to $ 524, resulting in a total epoxy cost of $ 1,007,000, down from $ 2,610,000.

Exterior Cell

The exterior cell has a longer span length (6.0 cm) than interior cell. A thicker wall is required to resist the hydrostatic pressure. Calculations show that a 6 mm wall thickness with 3/8” corner radius is required to have a working stress below 1,000 psi as shown in Fig 5 and Fig 6. The stress is mostly in a bending nature. We were interested to find a different profile of exterior cell, which will shift the bending type stress to the hoop type stress, to make the structure more efficient. A semi-circular shape seems very promising. Fig 6 shows the calculation results based on the 19 psi load. The maximum stress is around 650 psi with a 3 mm exterior wall with a semi-circular shape. The stress reduction, again, is almost 40 %.

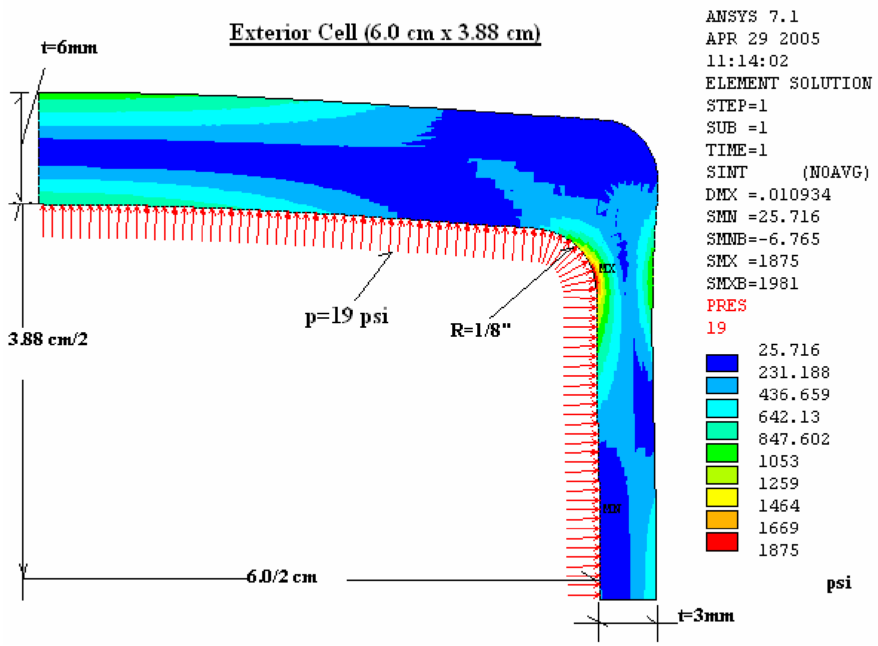

Fig 5 The exterior cell with a 6 mm wall & 1/8" corner radius (initial concept)

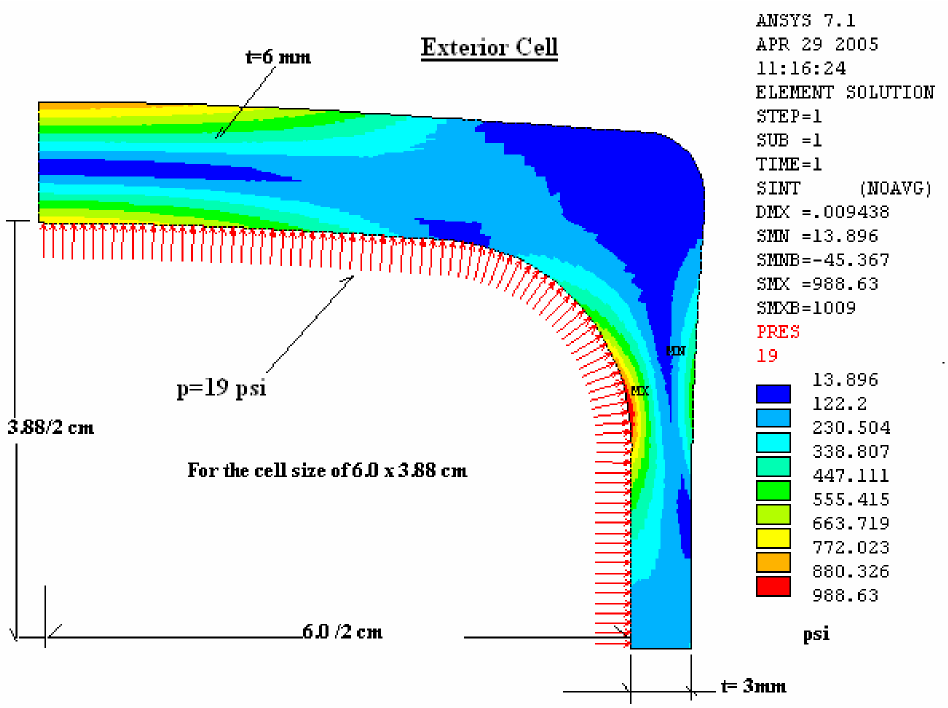

Fig 6The exterior cell with a 6 mm wall & 3/8" corner radius (larger radius)

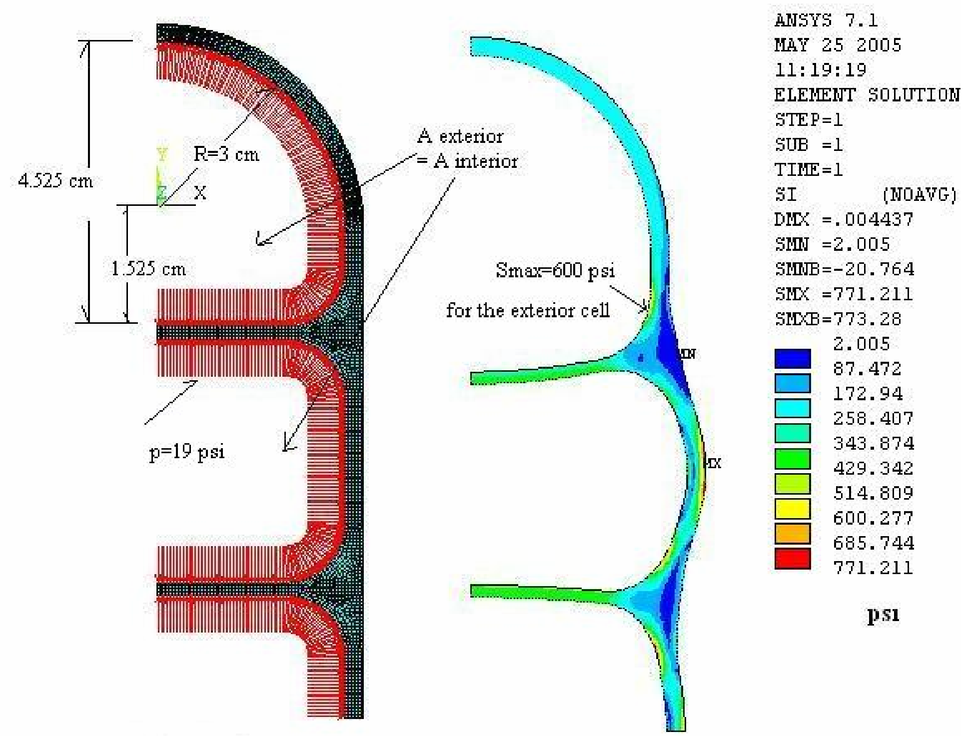

Fig 7 A semi-circular shape for the exterior cell

Conclusion

By increasing the corner radius to 3/8" with a scalloped back side for the interior cell, we've achieved:

1) Increased Safety factor (SF) of the buckling by 100% for a filled 32-planes block.
2) Reduced the working stress (under 19 psi) by 50%.
3) Maintained a same amount of material compared with the 2005 initial design.

We also suggest how planes can be glued together effectively and economically.

For the end cell, a semi-circular head will maintain the stress around 600 psi with a 3 mm wall. The hoop end cell saves a total of 8.3 tons of PVC, at a 2004 cost of 19,800 $. For either end cell shape, a separate die must be acquired. One can also expect the extrusion with a uniform outer wall thickness (3mm) to make it easier to produce straight product. Fig 8 shows the stress for both exterior and interior cell with a 3/8" corner radius and a scalloped back side. The maximum stress is around 800 psi. Fig 9 is a 5 cells profile with a scallop back side, for a possible use for test production and studies before committing to either of the 32 cell dies.

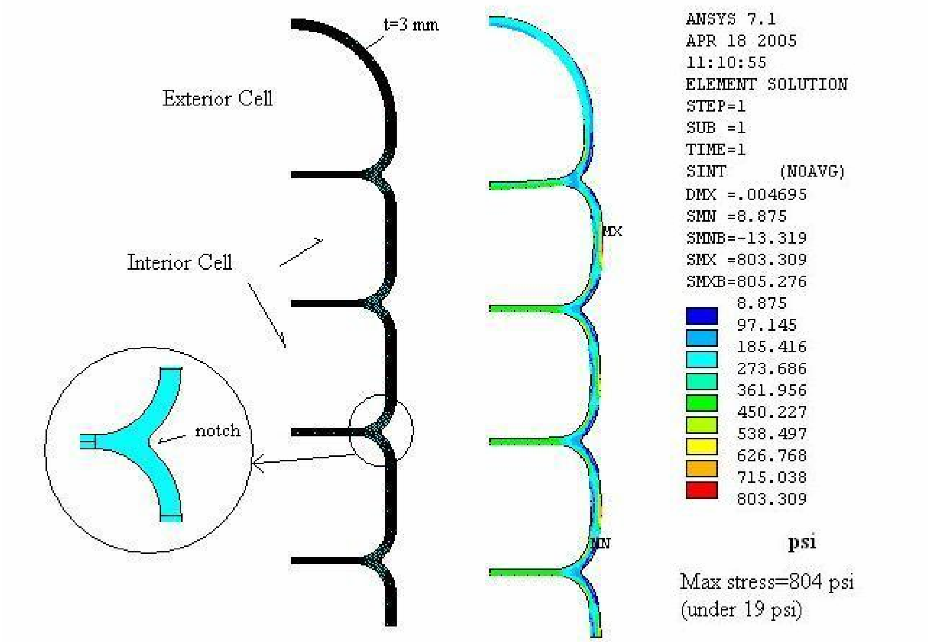

Fig 8 The stress for both interior and exterior cell under19 psi

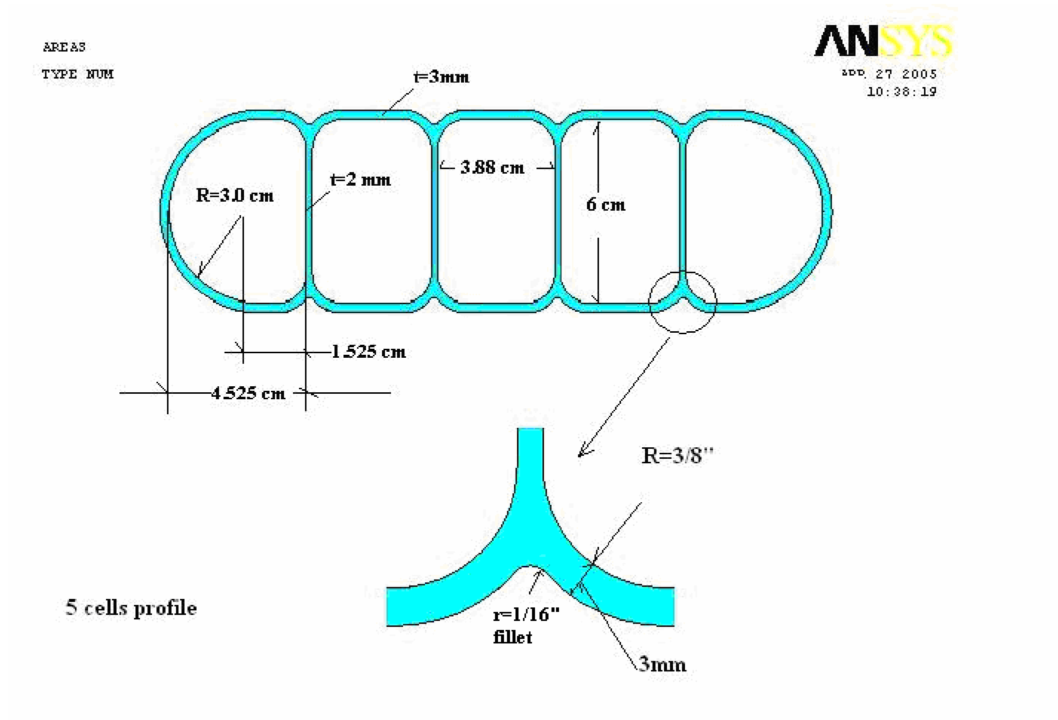

Fig 9The sketch of 5 cells sample

<u>Appendix A</u>

A Stability Calculation for the Cell profile
with a 3/8" Corner Radius and Scallop backside
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June 3, 2005

Introduction

The earlier study indicates that the cell profile with a 3/8" corner radius & scallop backside will reduced the stress by almost 50% without adding any extra material. The material surrounding the low stress area is redistributed to the high stress area to make the structure more efficiency for a given load. However, a concern is raised that the material removed is located at the backside of the plane. The structure stability needs to be re-evaluated to understand this implication.

Modeling & Calculation Result

A FEA model with a shell element is created with approximately 0.26e6 nodes for a 32 planes structure. The boundary condition is considered to be "top free and bottom fixed "(free standing) with a filled (wet) case. The calculations were done for the cases of 8, 16, 24 and 32 planes as summarized from Fig A-1 through Fig A-3. The result indicates that SF of the buckling is improved significantly. The cell profile with a larger corner radius reduces the effective length of the web and results a shear stiffness increase of the horizontal plane. The glued planes will behavior more towards a solid block type of structure whose stiffness is increased much fast than the weight as more planes added, rather than a "wet spaghetti" with a weak connection between planes as seen in the case of 1/8 corner radius.

The buckling calculation is also done for an unfilled (dry) 8 planes block for a both fully glued case (SF=5) and a skip glued case (SF=4.6) as shown in Fig A-4 and Fig A-5. The difference is about 10%. The bowing calculation is also done for the 32 filled planes as shown in Fig A-6 and Fig A-7. The accumulate deflection is about 62 mils occurring at about ~ 1(m) from the ground and the maximum stress is about 1,000 psi.

Conclusion

It seems to us that the 3/8" corner radius & scallop backside offers a superior structure performance in terms of the stress and stability with a minimum cost. This extra boost for the buckling safety factor is extremely valuable. Once the creep data becomes available for the proposed PVC material, we should anticipate less change required for the structure in question.

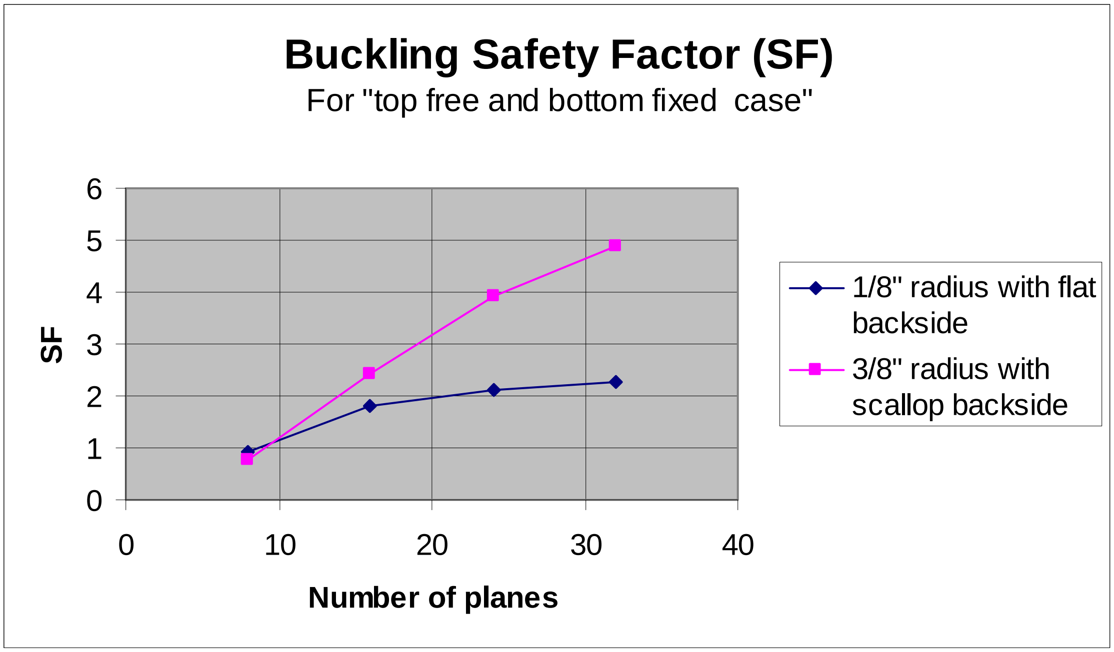

Fig A-1 Comparison of SF for a buckling calculation

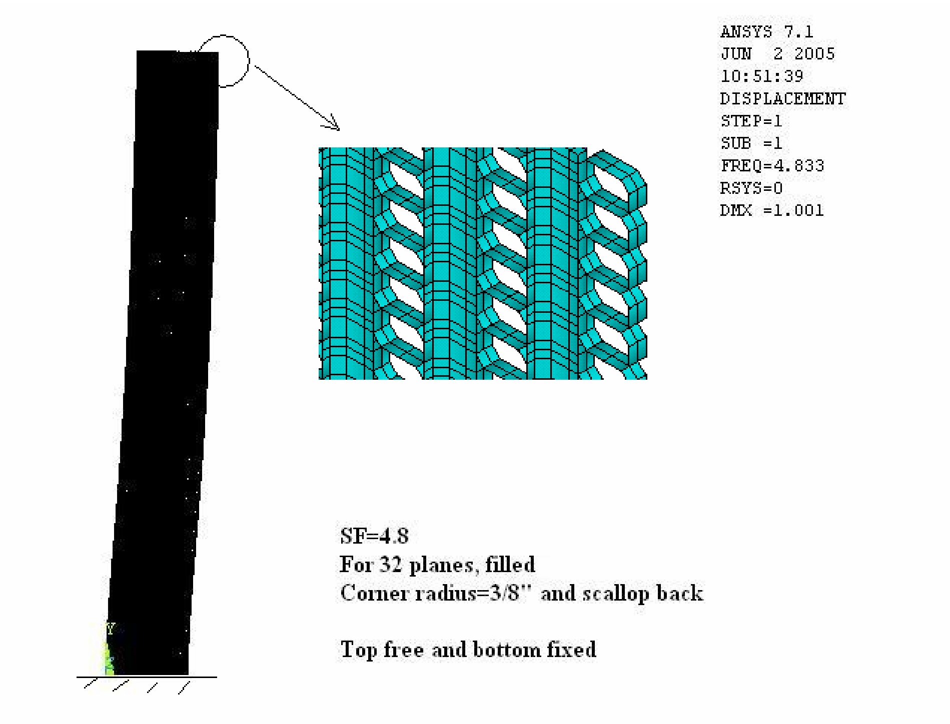

Fig A-2 The Buckling calculation for 32 planes (filled) with 3/8 " corner radius & scallop backside

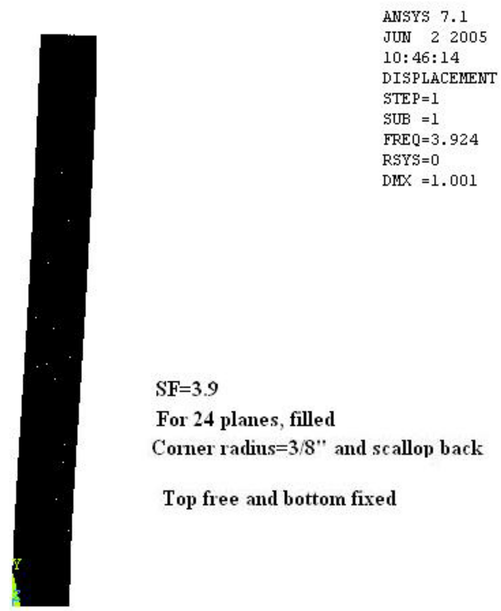

Fig A-3 The Buckling calculation for 24 planes (filled) with 3/8 " corner radius & scallop backside

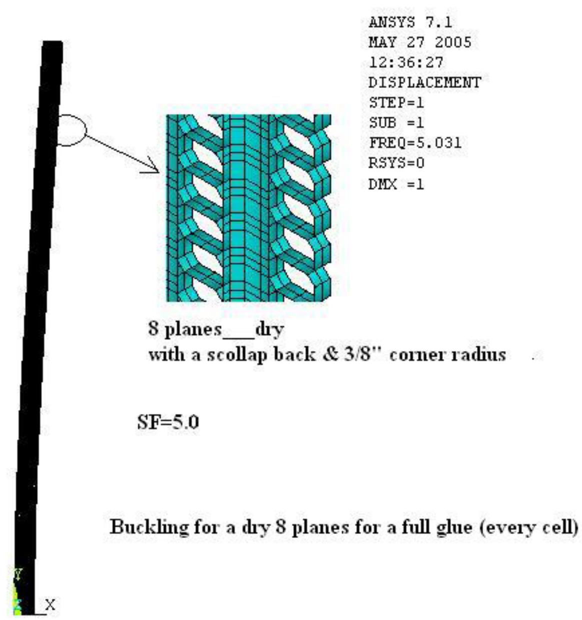

Fig A-4 The Buckling calculation for unfilled 8 planes (dry) __fully glued with 3/8 " corner radius & scallop backside

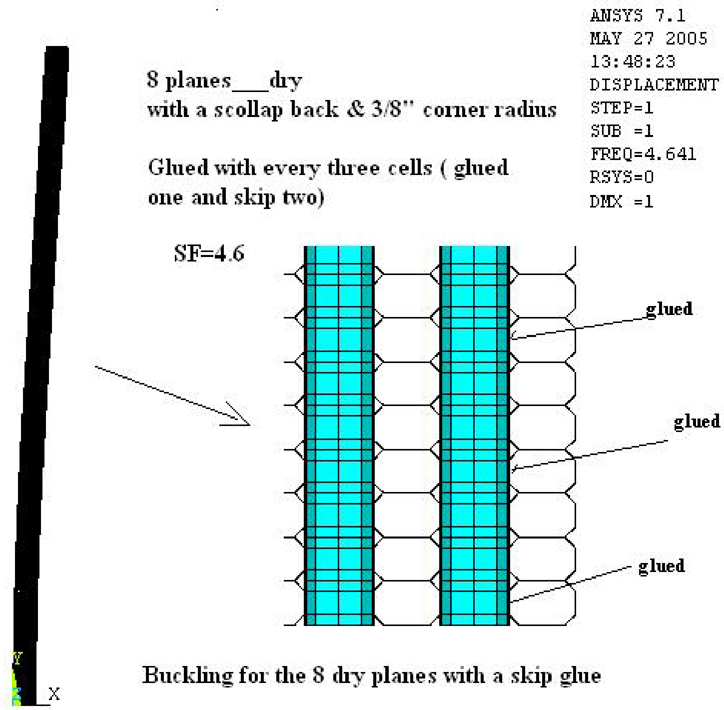

Fig A-5 The Buckling calculation for unfilled 8 planes (dry) __skip glued With 3/8" corner radius & scallop backside

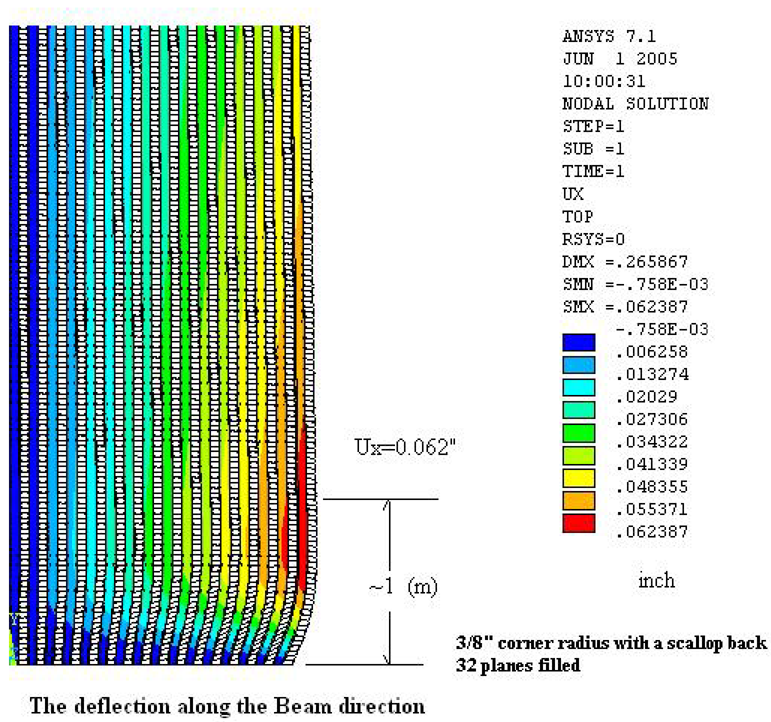

Fig A-6 The deflection calculation along the beam direction for 32 planes (filled) with 3/8 " corner radius & scallop backside

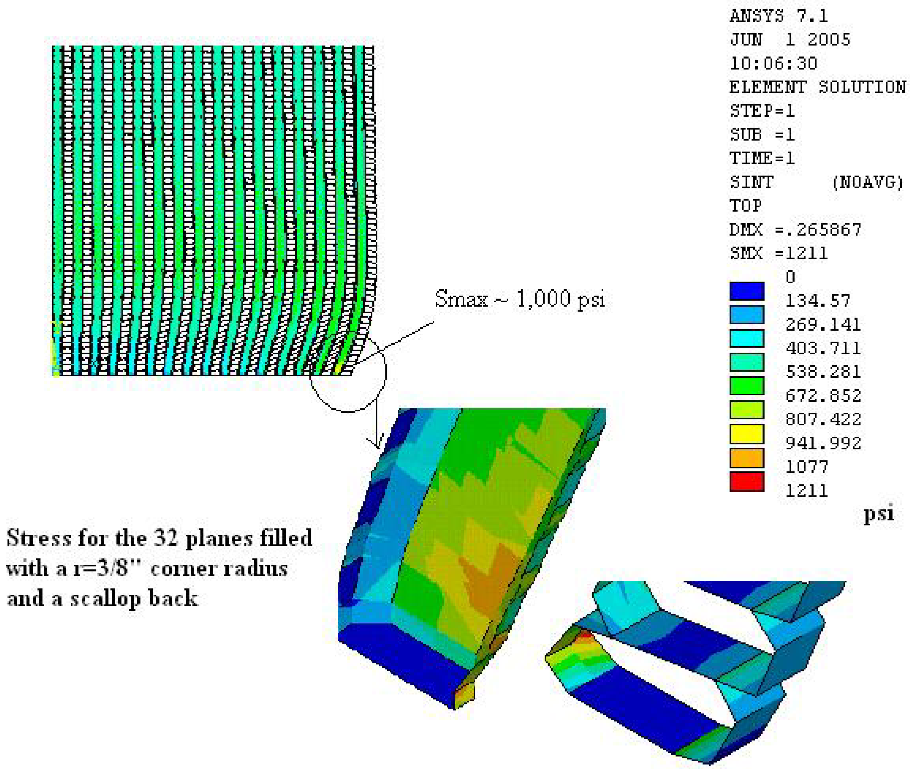

Fig A-7 The stress calculation along the beam direction for 32 planes (filled) with 3/8 " corner radius & scallop backside